SEMICONDUCTOR LASER DEVICE AND METHOD FOR FABRICATING THE SAME

BACKGROUND OF THE INVENTION

The present invention relates to semiconductor laser devices and methods for fabricating the devices, and more particularly relates to semiconductor laser devices which are used as a light source for the reading or writing of data from or on optical storage mediums such as compact discs and digital versatile discs, and methods for fabricating the devices.

Typical digital-versatile-disc (hereinafter referred to as "DVD") players need to function to play back compact discs (hereinafter referred to as "CDs") in addition to DVDs, and also have to function to replay, and store data on, recordable CDs (CD-Rs) which have become widespread rapidly in recent years.

As a light for replaying DVDs, a red laser beam with a wavelength in the 650 nm band is employed, while an infrared laser beam with a wavelength in the 780 nm band is used as a light for playing back CDs and CD-R discs. In the currently available DVD players, therefore, two semiconductor laser diodes are incorporated: one is a red semiconductor laser diode for generating a red laser beam and the other is an infrared semiconductor laser diode for generating an infrared laser beam.

With an increasing demand for smaller personal computers and other information equipment, DVD players also need to be reduced further in size and thickness. To that end, it is indispensable to reduce the size and thickness of optical pickup. Methods for reducing optical pickup in size and thickness include optical system simplification.

As a method for simplifying an optical system, integration of a red semiconductor laser diode and an infrared semiconductor laser diode is available. The current DVD

players include two optical systems: one for a red semiconductor laser diode and the other for an infrared semiconductor laser diode. Integration of the red semiconductor laser diode and the infrared semiconductor laser diode allows one optical system to be shared, thereby realizing an optical pickup system of smaller size and thickness.

For instance, as one example of the integration of a red semiconductor laser diode and an infrared semiconductor laser diode, a so-called monolithic semiconductor laser diode array which is integrated on a substrate is disclosed in Japanese Laid-Open Publication No. 11-186651.

Japanese Laid-Open Publication Nos. 11-144307 and 11-149652 disclose another example, in which hybrid integration of two semiconductor laser chips, one for a red laser and the other for an infrared laser, enables an optical system to be shared in an optical pickup system.

Nevertheless, in the conventional monolithic two-wavelength laser diode array, the respective active layers of the laser diodes have different compositions and thus have to be grown in different process steps, which results in the problem of low yields. In particular, when high-output laser diodes are monolithically integrated, yields decrease significantly.

Moreover, it is very difficult, in the viewpoint of crystal growth, to monolithically integrate a gallium nitride (GaN)-based blue laser diode, which is used in high density DVDs, and an aluminum gallium indium phosphide (AlGaInP)-based red laser diode, which is used in typical (conventional) DVDs.

The conventional hybrid optical pickup, on the other hand, have the problem that when the red semiconductor laser chip and the infrared semiconductor laser chip are assembled using assembly equipment, it is difficult to control and optimize the locations of active layers of the semiconductor laser chips and the distance between the light emitting points thereof.

In recent years, mounting methods in which a fluidic self-assembly (hereinafter referred to as "FSA") technique is used have been developed as one type of device-mounting method.

In the FSA technology, devices (hereinafter referred to as "function blocks") ranging in size from 10 μm to several hundred μm and having given shapes are suspended into a liquid to form a slurry. The liquid (suspension) in the form of slurry is poured over the surface of a substrate in which recessed portions have been formed. The recessed portions are substantially the same as the function blocks in size and shape. In this manner, the function blocks that have been spread in the liquid are settled into the recessed portions and thereby mounted onto the substrate.

The FSA technology is disclosed in USP5,545,291, USP5,783,856, USP5,824,186 and USP5,904,545, for example.

SUMMARY OF THE INVENTION

An object of the present invention is therefore that by focusing attention on the FSA technology, in a hybridly-integrated semiconductor laser chip array, the distance between the respective emission points of the semiconductor laser chips can be controlled in a self-aligned manner.

To achieve the object, a semiconductor laser device according to the present invention has the structure in which semiconductor laser chips whose emission directions are aligned are disposed in recessed portions formed in the principal surface of a substrate.

Specifically, a first inventive semiconductor laser device includes: a substrate having a plurality of recessed portions in its principal surface, and a plurality of semiconductor laser chips each disposed in one of the recessed portions. The semiconductor laser chips are a facet-emitting type in which a laser beam is emitted from a

facet, and the recessed portions are formed so that the respective emission directions of the semiconductor laser chips are aligned with each other.

In the first inventive semiconductor laser device, the semiconductor laser chips are disposed in the respective recessed portions formed in the principal surface of the substrate, and in addition the recessed portions are formed so that the respective emission directions of the semiconductor laser chips are aligned with each other. Thus, only by disposing the semiconductor laser chips into the recessed portions in the substrate, the locations of the respective active layers of the semiconductor laser chips self-align with each other, and the respective light-emitting points of the semiconductor laser chips also self-align with each other at a uniform distance.

In addition, the semiconductor laser chips are capable of being integrated together, even if their constituents (compositions) differ from each other. Further, the recessed portions themselves function to align the emission directions of the semiconductor laser chips, such that wavefront aberration of a spot formed when the resultant semiconductor laser device is used in an optical pickup system can be reliably within an allowable range.

In the first inventive semiconductor laser device, two of the semiconductor laser chips preferably have mutually different emission wavelengths.

Also, in the first inventive semiconductor laser device, two of the semiconductor laser chips preferably have mutually different optical outputs.

In the first inventive semiconductor laser device, a notch, through which a laser-emitting portion of an associated one of the semiconductor laser chips is exposed, is preferably formed in the substrate.

Then, even if the semiconductor laser device has a structure in which each facet-emitting-type semiconductor laser chip is embedded in the recessed portion in the substrate, a laser beam can be obtained through the notch.

In this case, at least two said notches are preferably formed.

Also in this case, the notch preferably has the shape of a depression and the lower end of the notch preferably reaches the bottom face of an associated one of the recessed portions.

In the first inventive semiconductor laser device, the front facet side of each said semiconductor laser chip preferably differs in shape from the rear facet side thereof that faces the front facet side.

Then, when the semiconductor laser chips are disposed into the recessed portions, the front and rear ends of each semiconductor laser chip in its emission direction can be selectively positioned.

Further, in the first inventive semiconductor laser device, in each said semiconductor laser chip, optical output from its front facet is preferably equal to optical output from its rear facet.

Then, the emission direction for the semiconductor laser chips does not have to be selected, which further facilitates the manufacturing of the device.

In the first inventive semiconductor laser device, a recess electrode is preferably formed on the bottom face of each said recessed portion, a chip electrode is preferably formed on a face of each said semiconductor laser chip which faces the bottom face of the associated one of the recessed portions, and each said semiconductor laser chip is preferably electrically connected to the associated recess electrode via the chip electrode.

Then, even if each semiconductor laser chip is structured to have a chip electrode on its bottom face, an operating current can be reliably supplied to the semiconductor laser chip by establishing electrical connection with an associated recess electrode from the substrate bottom, for example.

In the first inventive semiconductor laser device, the semiconductor laser chips

preferably differ from each other in plan configuration, and the plan configurations of the recessed portions preferably vary according to the associated semiconductor laser chips.

Then, the respective semiconductor laser chips can be selectively disposed into the recessed portions formed in the substrate.

In this case, the plan configurations of the semiconductor laser chips preferably vary in accordance with their emission wavelengths. Then, a two-wavelength laser chip array can be reliably obtained.

Also in this case, the semiconductor laser chips preferably vary in shape in accordance with their optical outputs. Then, a laser chip array in which different functions, such as writing and reading, can be performed is reliably obtainable.

A second inventive semiconductor laser device includes: a substrate having a plurality of recessed portions in its principal surface, and a plurality of semiconductor laser chips each disposed in one of the recessed portions. A chip electrode is formed on a face of each said semiconductor laser chip which faces the bottom face of the associated one of the recessed portions, and a recess electrode is formed on the bottom face of each said recessed portion in such a manner that an end portion of the recess electrode extends beyond the principal surface of the substrate.

In the second inventive semiconductor laser device, the semiconductor laser chips are disposed in the respective recessed portions formed in the principal surface of the substrate, and each recess electrode is formed so that an end portion thereof extends beyond the principal surface of the substrate. Then, even after the semiconductor laser chips have been disposed in the recessed portions in the substrate, electrical connection for the chip electrodes formed on the respective bottoms of the semiconductor laser chips is easily established from the principal surface side of the substrate.

In addition, the semiconductor laser chips are capable of being integrated together,

even if their constituents (compositions) differ from each other. Further, the recessed portions themselves can function to align the emission directions of the semiconductor laser chips, such that wavefront aberration of a spot formed when the resultant semiconductor laser device is used in an optical pickup system can be reliably within an allowable range.

In the second inventive semiconductor laser device, the recess electrode is preferably so formed as to be shared by the semiconductor laser chips.

Then, even if the semiconductor laser chips have mutually different emission wavelengths, a common chip electrode can be formed on the bottom faces of the semiconductor laser chips that forms a laser chip array.

An inventive method for fabricating a semiconductor laser device includes the steps of: (a) forming a plurality of recessed portions in the principal surface of a substrate, and (b) spreading a plurality of semiconductor laser elements in the form of chips in a liquid and pouring the semiconductor-laser-element-spread liquid over the principal surface of the substrate, thereby allowing the semiconductor laser elements to be disposed into the respective recessed portions in a self-aligned manner. The semiconductor laser elements are a facet-emitting type in which a laser beam is emitted from a facet, and in the step (a), the recessed portions are formed so that the respective emission directions of the semiconductor laser elements are aligned with each other.

According to the inventive semiconductor laser device fabrication method, by using a so-called FSA technique, a liquid in which semiconductor laser elements have been spread is poured over the principal surface of a substrate so that the semiconductor laser elements are disposed into recessed portions in a self-aligned manner. Thus, only by disposing the semiconductor laser elements into the recessed portions in the substrate, the locations of the respective active layers of the semiconductor laser elements self-align with

each other, and the respective light-emitting points of the semiconductor laser elements also self-align with each other at a uniform distance.

In addition, the semiconductor laser elements are capable of being integrated together, even if their constituents (compositions) differ from each other. Further, the recessed portions themselves function to align the emission directions of the semiconductor laser elements, such that wavefront aberration of a spot formed when the resultant semiconductor laser device is used in an optical pickup system can be reliably within an allowable range.

In the inventive semiconductor laser device fabrication method, the step (a) preferably includes the step of forming in the substrate a notch through which a laser-emitting portion of an associated one of the semiconductor laser elements is exposed.

Then, even if each facet-emitting-type semiconductor laser element is disposed in the recessed portion in the substrate, a laser beam can be obtained through the notch.

In the inventive method, in the step (a), the recessed portions are preferably so formed as to vary in plan configuration in accordance with the shapes of the associated semiconductor laser elements.

Then, the semiconductor laser elements with mutually different emission wavelengths can be selectively disposed into the recessed portions formed in the substrate even by a FSA process, which allows a two-wavelength laser chip array, for example, to be obtained reliably.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1A** through **1C** schematically illustrate a semiconductor laser device in accordance with an embodiment of the present invention. FIG. **1A** is a plan view, FIG. **1B** is a right-side view, and FIG. **1C** is a front view.

FIGS. **2A** and **2B** schematically illustrate a semiconductor laser device in accordance with a first modified example of the embodiment of the present invention. FIG. **2A** is a plan view, and FIG. **2B** is a right-side view.

FIG. **3** is a plan view schematically illustrating a semiconductor laser device in accordance with a second modified example of the embodiment of the present invention.

FIG. **4** is a plan view schematically illustrating a semiconductor laser device in accordance with a third modified example of the embodiment of the present invention.

FIGS. **5A** through **5C** are plan views schematically illustrating recessed portions and recess electrodes formed in respective substrates of semiconductor laser devices in accordance with the embodiment of the present invention.

FIGS. **6A** and **6B** illustrate a substrate, being in a wafer state, of semiconductor laser devices according to the embodiment of the present invention. FIG. **6A** is a plan view, and FIG. **6B** is a partial enlarged plan view.

FIGS. **7A** through **7F** are cross-sectional views illustrating process steps in a method for fabricating a semiconductor laser device in accordance with the embodiment of the present invention.

FIG. **8** is a diagram schematically illustrating equipment for mounting semiconductor laser chips which is used in the semiconductor laser device fabrication method in accordance with the embodiment of the present invention.

FIG. **9** is an enlarged partial plan view illustrating a substrate in a wafer state in which function blocks have been disposed according to the semiconductor laser device fabrication method in accordance with the embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinafter, an embodiment of the present invention will be described with

reference to the accompanying drawings.

FIGS. **1A** through **1C** illustrate a semiconductor laser device in accordance with an embodiment of the present invention. FIG. **1A** shows a plan configuration, FIG. **1B** shows a right-side configuration, and FIG. **1C** shows a front configuration.

As shown in FIG. **1A**, a semiconductor laser device **100** in accordance with this embodiment includes a substrate **10**, which is made of silicon (Si), for example, and which has in its principal surface first and second recessed portions **10a** and **10b** formed at a distance from each other.

Disposed in the first recessed portion **10a** is a first semiconductor laser chip **11** in the form of a function block, which emits an infrared laser beam, for example. Disposed in the second recessed portion **10b** is a second semiconductor laser chip **12** in the form of a function block, which emits a red laser beam, for example.

In this embodiment, the material forming the substrate **10** is not limited to silicon, but the substrate **10** may be made of gallium arsenide (GaAs) or silicon carbide (SiC), for example, and is preferably made of material having excellent thermal conductivity. The material forming the substrate **10** may be selected in accordance with the type of function block and the application of the semiconductor laser device **100**, for example.

The emission wavelengths of the first and second semiconductor laser chips **11** and **12** are not limited to the above-described combination. For example, any two laser beams may be selected from infrared, red, and blue laser beams. Moreover, a third recessed portion may be so formed in the substrate **10** as to be located alongside, e.g., the first recessed portion **10a**, and three semiconductor laser chips that emit mutually different laser beams may be respectively disposed into those recessed portions. Furthermore, four or more recessed portions may be formed in the substrate **10**, and laser chips may be disposed into the respective recessed portions.

The semiconductor laser device **100** is applicable in an optical pickup system (not shown) for use in the reading or writing of data from or on an optical disc. In this embodiment, the semiconductor laser chips **11** and **12** are both so-called facet-emitting semiconductor laser chips in which a grown semiconductor layer facet emits a laser beam. As shown in FIGS. **1B** and **1C**, the semiconductor laser chips **11** and **12** are arranged so that laser beams emitted from their respective laser-emitting facets **11a** and **12a** enter an objective lens incorporated in the optical pickup system.

This embodiment is therefore characterized in that as shown in FIG. **1B**, first and second notches **10c** and **10d** are formed in the substrate **10** in such a manner that the respective laser-emitting portions (resonator facets) **11c** and **12c** of the laser-emitting facets of the first and second semiconductor laser chips **11** and **12** are exposed through the first and second notches **10c** and **10d**. With the notches **10c** and **10d** formed in the substrate **10** in this manner, even if the semiconductor laser chips **11** and **12** are so structured as to be fitted into the recessed portions **10a** and **10b** in the substrate **10**, the respective emitted lights can be obtained as shown in FIG. **1C**.

Further, third and fourth notches **10e** and **10f** are also formed in the substrate **10** so that laser beams for a power monitor are obtained from the respective rear facets **11b** and **12b** of the semiconductor laser chips **11** and **12** through the third and fourth notches **10e** and **10f**. The rear facets **11b** and **12b** are located opposite to the laser-emitting facets **11a** and **12a**, respectively. The third and fourth notches **10e** and **10f** for the power monitor are not necessarily needed, and whether they should be formed or not may be determined depending upon the application of the semiconductor laser device **100**.

In this embodiment, as shown in FIG. **1B**, the respective plan configurations of the first and second semiconductor laser chips **11** and **12** in the form of the function blocks are rectangular, and the respective sections thereof taken in a vertical direction with respect to

their emission directions are in the shape of a trapezoid.

The respective configurations of the function blocks are not limited to this, but may be varied depending upon the application and function. Specifically, the plan configuration of each function block may be, e.g., a square or a circle; or a shape having 2-fold rotational symmetry such as a parallelogram, an ellipse, or an oval; or a shape having 1-fold rotational symmetry such as a trapezoid. It should be however noted that in the case of a square or a circle, it becomes slightly difficult to align the respective emission directions of the function blocks.

As described above, in this embodiment, the semiconductor laser chips **11** and **12**, which differ from each other in emission wavelength and have been formed into the function blocks, are arranged so that the respective laser-emitting directions are substantially parallel with each other. This enables the laser-emitting portions **11c** and **12c** of the semiconductor laser chips **11** and **12** to self-align, such that wavefront aberration created in the optical system for the laser beams can be reliably reduced.

It should be noted that the first and second semiconductor laser chips **11** and **12** may be so structured as to have the same emission wavelength and different optical output values.

Also, the first and second semiconductor laser chips **11** and **12** may be established in such a manner that optical output from the laser-emitting facet **11a** is equivalent to optical output from the rear facet **11b**, and that optical output from the laser-emitting facet **12a** is equivalent to optical output from the rear facet **12b**. Then, it is not necessary to make a distinction between the front and rear directions for each of the first and second semiconductor laser chips **11** and **12**, which facilitates the process step of disposing the semiconductor laser chips **11** and **12** into the first and second recessed portions **10a** and **10b**.

Furthermore, the locations in which the semiconductor laser chips **11** and **12** in the form of the function bocks are disposed are not limited to this embodiment.

(First modified example)

Hereinafter, a first modified example of the embodiment of the present invention will be described with reference to the accompanying drawings.

FIGS. **2A** and **2B** illustrate a semiconductor laser device in accordance with a first modified example of the embodiment of the present invention. FIG. **2A** shows a plan configuration, and FIG. **2B** shows a right-side configuration. In FIGS. **2A** and **2B**, the same members as those shown in FIGS. **1A** and **1B** are identified by the same reference numerals and the descriptions thereof will be omitted herein.

As shown in FIGS. **2A** and **2B**, in a semiconductor laser device **100A** according to the first modified example, the width dimension of a second semiconductor laser chip **12A**, which is the dimension in a vertical direction with respect to its emission direction, is made smaller than the width dimension of a first semiconductor laser chip **11**. This facilitates the process of selectively disposing the semiconductor laser chips **11** and **12A** that have mutually different laser-emitting wavelengths or mutually different optical output values. Also in this case, the laser-emitting facets **11a** and **12a** of the semiconductor laser chips **11** and **12A** are located in alignment with each other, and the heights of their laser-emitting portions **11c** and **12c** are made equal to each other, for example.

(Second modified example)

Next, a second modified example of the embodiment of the present invention will be described with reference to the accompanying drawings.

FIG. **3** illustrates the plan configuration of a semiconductor laser device in accordance with a second modified example of the embodiment of the present invention. In FIG. **3**, the same members as those shown in FIG. **1A** are identified by the same

reference numerals.

As shown in FIG. 3, in a semiconductor laser device **100B** according to the second modified example, the length dimension of a second semiconductor laser chip **12B**, which is the dimension in a parallel direction with respect to its emission direction, is made smaller than the length dimension of a first semiconductor laser chip **11**. This also facilitates the process of disposing in the desired locations the semiconductor laser chips **11** and **12B** that have mutually different laser-emitting wavelengths or mutually different optical output values. Also in this case, the laser-emitting facets **11a** and **12a** of the semiconductor laser chips **11** and **12B** are located in alignment with each other, and the heights of their laser-emitting portions **11c** and **12c** are made equal to each other, for example.

(Third modified example)

Next, a third modified example of the embodiment of the present invention will be described with reference to the accompanying drawings.

FIG. **4** illustrates the plan configuration of a semiconductor laser device in accordance with a third modified example of the embodiment of the present invention. In FIG. **4**, the same members as those shown in FIG. **1A** are identified by the same reference numerals.

In a semiconductor laser device **100C** according to the third modified example, first and second semiconductor laser chips **11C** and **12C** are both high-output laser chips, and their respective end portions located on their rear facet **11b** and **12b** sides differ in plan configuration from their respective end portions located on their laser-emitting facet **11a** and **12a** sides which are situated opposite to the rear facets **11b** and **12b** sides. Further, as in the second modified example, the length dimension of the second semiconductor laser chip **12C** is made smaller than the length dimension of the first semiconductor laser chip

11C.

In a typical high-output laser chip, a laser output value (power) on the laser-emitting facet side thereof differs greatly from a laser output value on its rear facet side. The laser-emitting facet and the rear facet thus have to be positively distinguished from each other.

In the third modified example, therefore, as shown in FIG. **4**, the semiconductor laser chips **11C** and **12C** are formed so that their laser-emitting facets **11a** and **12a** differ in shape from their rear facets **11b** and **12b**, respectively, which allows the emission directions of the semiconductor laser chips **11C** and **12C** to be aligned reliably.

It should be noted that the plan configurations of the semiconductor laser chips **11C** and **12C** shown in FIG. **4** are merely an example, and thus are not limited to those shapes so long as the plan configurations of their respective front and rear end portions are asymmetrical.

In the case where both p-side and n-side electrodes serving as chip electrodes for the first and second semiconductor laser chips **11** and **12** are formed at the principal surface side of the substrate **10**, electrodes (recess electrodes) do not have to be formed on the respective bottom faces of the recessed portions **10a** and **10b**.

However, recess electrodes have to be formed on the bottom faces of the recessed portions **10a** and **10b** when a p-side chip electrode and an n-side chip electrode are respectively formed on the upper and bottom faces of each of the semiconductor laser chips **11** and **12** in such a manner that the chip electrodes face each other.

FIGS. **5A** through **5C** illustrate the respective plan configurations of recess electrodes formed in three different ways.

FIG. **5A** illustrates recess electrodes according to a first example. As shown in FIG. **5A**, in order to drive the first and second semiconductor laser chips **11** and **12**, first and

second recess electrodes **21** and **22** made of low-melting-point metal such as solder material are respectively formed on the bottom faces of the recessed portions **10a** and **10b** in the substrate **10**.

After the semiconductor laser chips **11** and **12** in the form of the function blocks have been disposed into the respective recessed portions **10a** and **10b** in the substrate **10** by a FSA technique, which will be described later, the first and second recess electrodes **21** and **22** are heated to a degree at which the solder material melts. In this manner, the chip electrodes of the semiconductor laser chips **11** and **12** are electrically connected to the recess electrodes **21** and **22**, respectively.

Further, the first and second recess electrodes **21** and **22** are electrically connected to the outside of the substrate **10** through vias **130**, which may be formed by, for example, filling, with conductive material, through-holes which are formed in the substrate **10** under the recess electrodes.

Next, FIG. **5B** illustrates recess electrodes according to a second example. As shown in FIG. **5B**, extended portions **21a** and **22a** are respectively formed on the outer sides of first and second recess electrodes **21** and **22** which are in parallel with the emission directions. The extended portions **21a** and **22a** extend from the bottom faces of the recessed portions **10a** and **10b** in the substrate **10** beyond the principal surface of the substrate **10**. Since the recess electrodes **21** and **22** have the respective extended portions **21a** and **22a** in this manner, electrical connection for the chip electrodes formed on the respective bottom faces of the semiconductor laser chips can be established from the principal surface side of the substrate **10** without forming vias **130** in the lower portion of the substrate **10**.

Next, FIG. **5C** illustrates recess electrodes according to a third example. As shown in FIG. **5C**, a shared recess electrode **23** is formed on the bottom faces of the first and

second recessed portions **10a** and **10b** so that the shared recess electrode **23** extends across the boundary between the bottom faces. Also in this example, an extended portion **23a** is formed on the outer side of a first recess electrode **21** which is in parallel with the emission direction, in such a manner that the extended portion **23a** extends from the bottom face of the first recessed portion **10a** beyond the principal surface of the substrate **10**. With the shared recess electrode **23** so formed, even if the first and second semiconductor laser chips **11** and **12** have mutually different emission wavelengths, the semiconductor laser chips, which forms a laser chip array, are allowed to have a common chip electrode on their bottom faces.

In forming the shared recess electrode **23**, if the boundary portion between the first and second recessed portions **10a** and **10b** in the substrate **10** is removed so that the boundary portion has substantially the same height as the bottom faces of the recessed portions **10a** and **10b**, then it becomes easier to form the shared recess electrode **23**.

The foregoing has described how to make conductive the bottom-face electrodes of the chip electrodes of the semiconductor laser chips. For the upper-face chip electrodes that are exposed at the principal surface side of the substrate **10**, interconnection can be relatively easily established by wire bonding.

(Fabrication method)

Hereinafter, it will be described how to fabricate a semiconductor laser device **100** having the above-described structure with reference to the accompanying drawings.

As show in FIGS. **1A** through **1C**, the semiconductor laser device **100** according to the present invention is characterized in that by disposing the semiconductor laser chips **11** and **12** in the form of the function blocks into the recessed portions **10a** and **10b** formed in the substrate **10**, their respective laser-emitting portions **11c** and **12c** can self-align.

The semiconductor laser chips **11** and **12** in the form of the function blocks can be

disposed into the respective recessed portions **10a** and **10b** formed in the substrate, manually or by assembly equipment.

However, in this embodiment, the efficiency of the process step of disposing (mounting) the laser chips is significantly increased by using the above-mentioned FSA technology.

First, a method for forming the inventive recessed portions on the principal surface of a substrate will be described.

FIGS. **6A** and **6B** illustrate a wafer **10A**, which will serve as a substrate for semiconductor laser devices according to the embodiment of the present invention, which is made of silicon, gallium arsenide, or silicon carbide, and in which a plurality of recessed portions have been formed. FIG. **6A** illustrates the plan configuration of the wafer **10A**, and FIG. **6B** shows on an enlarged scale a part of the wafer **10A** shown in FIG. **6A**.

As shown in the enlarged partial view in FIG. **6B**, a plurality of the first recessed portions **10a** and a plurality of the second recessed portions **10b**, which are adjacent to the first recessed portions **10a**, are arranged in the principal surface of the wafer **10A** as first and second recess rows, respectively, in such a manner as to be located in parallel with each other at a distance from each other in the longitudinal directions (laser-emitting directions) of the recesses. Semiconductor laser chips in the form of function blocks will be disposed into the first and second recessed portions **10a** and **10b**.

In the principal surface of the wafer **10A**, a groove **10g** is also formed in the region between any two of the first recessed portions **10a** which are adjacent to each other in the longitudinal direction as well as in the region between any two of the second recessed portions **10b** which are adjacent to each other in the longitudinal direction. The grooves **10g** will act as notches through which emitted light is obtained after the wafer **10A** is divided.

- Method for forming a substrate -

Hereinafter, an exemplary method for forming a substrate will be described.

FIGS. **7A** through **7F** are cross-sectional views illustrating process steps for forming recessed portions in a substrate of a semiconductor laser device in accordance with the embodiment of the present invention. Herein, a wafer **10A** made of silicon is used, and by focusing attention only on a first recessed portion **10a** formed in part of the wafer **10A**, the figures illustrate such part of the wafer **10A** in cross section taken in a vertical direction with respect to the emission direction.

As shown in FIG. **7A**, a mask film **30** of silicon dioxide (SiO_2) is deposited to a thickness of about 0.7 μm to 1 μm on the principal surface of the wafer **10A** by a CVD process, for example.

Next, as shown in FIG. **7B**, a resist pattern **31** is selectively formed by lithography. The resist pattern **31** has an opening pattern **31a** for the first recessed portions **10a** and an opening pattern (not shown) for grooves **10g** which will serve as notches.

Then, as shown in FIG. **7C**, with the resist pattern **31** acting as a mask, the mask film **30** is dry-etched using fluorocarbon, for example, as an etching gas, such that the opening pattern **30a** for the first recessed portions **10a** and the opening pattern (not shown) for the grooves **10g** are transferred to the mask film **30**.

Subsequently, as shown in FIG. **7D**, the resist pattern **31** is removed by ashing. Thereafter, as shown in FIG. **7E**, with the mask film **30** having the opening pattern **30a** acting as a mask, the wafer **10A** is dry-etched using chlorine (Cl_2) or hydrogen bromide (HBr), for example, as an etching gas, so that the first recessed portions **10a** are formed in the wafer **10A**. In this process step, the type of etching performed for the wafer **10A** is not limited to the dry etching, but the wafer **10A** may be wet-etched using a mixed solution of hydrofluoric acid and nitric acid. Second recessed portions **10b** and grooves connected

thereto are formed in the same manner as, and at the same time with, the first recessed portions **10b** and the grooves **10g** connected thereto.

Subsequently, as shown in FIG. **7F**, the wafer **10A** in which the recessed portions **10a** have been formed is washed with water, and then dried.

Thereafter, when recess electrodes are necessary, one of the recess electrodes shown in FIGS. **5A** through **5C** is formed.

- Method for mounting semiconductor laser chips -

Next, it will be described how to mount semiconductor laser chips.

A method for mounting semiconductor laser chips in accordance with this embodiment employs a FSA technique as a method for disposing the first and second semiconductor laser chips **11** and **12** in the form of the function blocks into the respective recessed portions **10a** and **10b** formed in the wafer **10A**. The use of the FSA technique enables the first and second semiconductor laser chips **11** and **12** in the form of the function blocks to be disposed in the desired locations precisely and highly efficiently.

In the FSA technology, function blocks are spread into a fluid (medium) such as water (H_2O) or methyl alcohol (CH_3OH). In the case of assembling two-wavelength laser chip arrays, therefore, the first and second semiconductor laser chips **11** and **12** preferably have different plan configurations. Specifically, it is preferable to form in the wafer **10A** recessed portions **10a** and **10b** in which the first and second semiconductor laser chips **11C** and **12C** of the third modified example shown in FIG. **4** can be disposed, for example.

Further, of the first and second semiconductor laser chips **11C** and **12C**, the laser chips having a larger plan dimension, that is, the first semiconductor laser chips **11C** are preferably disposed first.

Therefore, hereinafter, fabrication of a semiconductor laser device **100C** according to the third modified example will be described.

First, when recess electrodes have been formed on the bottom faces of the first and second recessed portions **10a** and **10b**, solder material is applied onto the recess electrodes. In the case where the recess electrodes are not formed, a thermosetting adhesive or a UV-setting adhesive, for example, may be applied.

FIG. **8** schematically shows equipment for mounting a plurality of semiconductor laser chips **11C** and **12C** that have been formed into function blocks, using a FSA technique.

As shown in FIG. **8**, the equipment includes a receptacle **50**, a wafer holder **51**, and a pump **60**. The receptacle **50** is used to contain a fluid in the form of slurry in which a plurality of semiconductor laser chips in the form of function blocks have been spread. The wafer holder **51** provided on the bottom of the receptacle **50** is capable of rotating and used to hold a wafer **10A** on its upper face. The pump **60** circulates the fluid in the form of slurry. The upper face of the wafer holder **51** is located slantingly with respect to the surface of the fluid.

The pump **60** is provided to circulate the fluid in the form of slurry inside the receptacle **50** by introduction of a nitrogen gas, for example, from a gas inlet portion **61**, and to pour the circulated fluid over the upper face of the wafer holder **51**.

Subsequently, a wafer **10A**, in which a plurality of first and second recessed portions **10a** and **10b** and grooves **10g** have been formed, is held on the wafer holder **51**.

Thereafter, a fluid in the form of slurry, in which a plurality of semiconductor laser chips **11C** have been spread, is poured over the entire principal surface of the wafer **10A** that is held in a slanting position. Since the fluid in the form of slurry is circulated by the pump **60**, the first semiconductor laser chips **11C** which are not disposed into the first recessed portions **10a** can be collected and reused any number of times.

In this method, if the wafer **10A** held in the fluid is rotated in its plane direction, the

first semiconductor laser chips **11C** are more likely to be disposed in the recessed portions.

Then, after it is confirmed that the mounting of the first semiconductor laser chips **11C** into the first recessed portions **10a** in the wafer **10A** has been completed, a plurality of second semiconductor laser chips **12C** in the form of function blocks are spread in a fluid, and the second semiconductor laser chips **12C** are disposed in second recessed portions **10b** formed in the wafer **10A** by operating the pump **60**.

FIG. **9** shows on an enlarged scale a part of the wafer **10A** in which the first and second semiconductor laser chips **11C** and **12C** have been disposed in the recessed portions **10a** and **10b**, respectively.

Thereafter, the first and second semiconductor laser chips **11C** and **12C** are secured. Specifically, when the first and second semiconductor laser chips **11C** and **12C** are secured by solder material or a thermosetting adhesive, the wafer **10A** is heated. When they are secured with a UV-setting adhesive, the entire principal surface of the wafer **10A** is irradiated with ultraviolet light.

Next, the wafer **10A** is cut using a dicing saw, for example, along dicing lines **40** indicated by broken lines in FIG. **9**, thereby cutting each semiconductor laser device **100C** from the wafer **10A**.

As described above, according to the semiconductor laser device fabrication method of this embodiment, the mounting process can be simplified significantly. In addition, since only the function blocks (semiconductor laser chips) that have been determined as being non-defective can be mounted, the cost of the semiconductor laser devices can be reduced.

Furthermore, the use of the FSA technology in the mounting of the semiconductor laser chips onto the wafer **10A** permits the semiconductor laser chips to be positioned in a self-aligned manner, which increases yields.